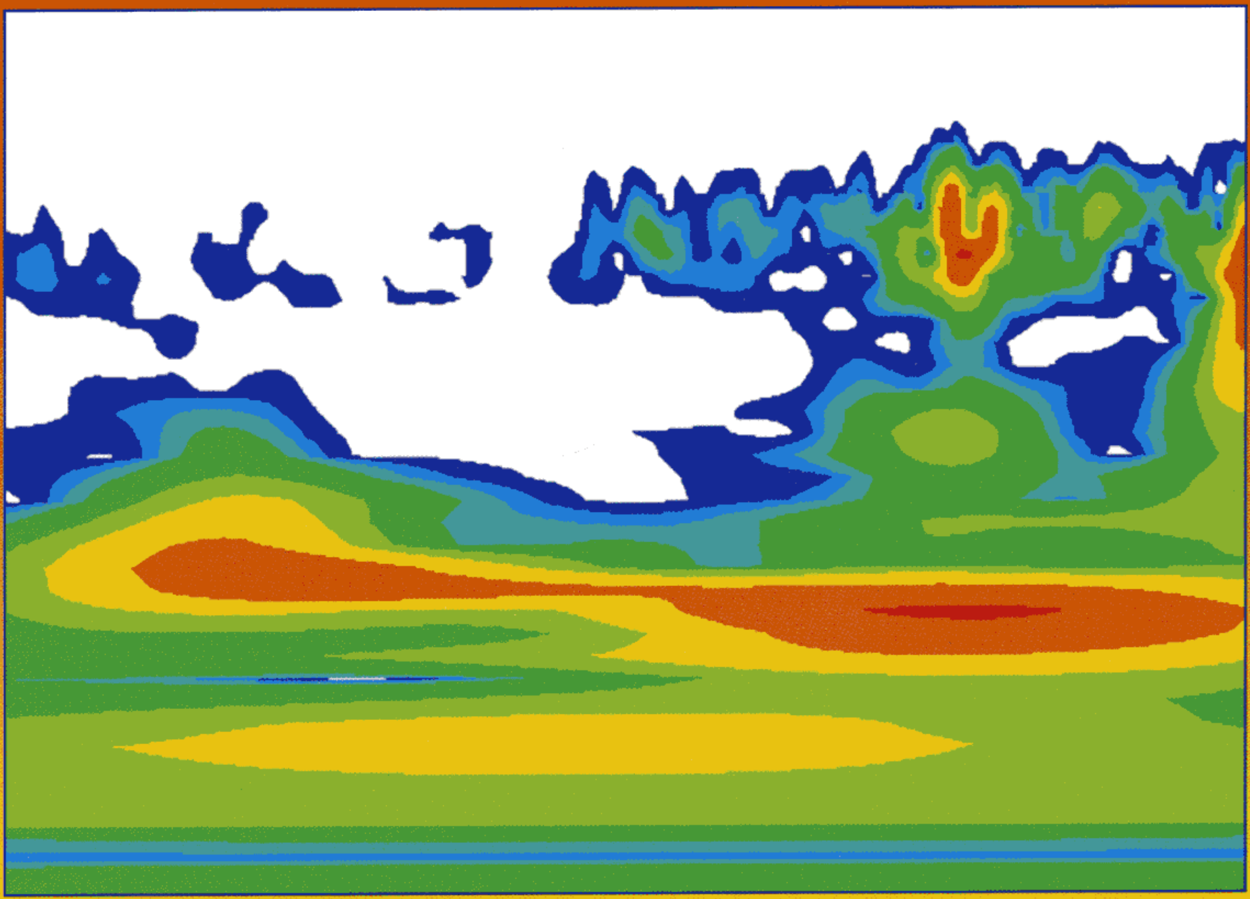
nuclear weapons journal



September/October 2003

■ Risk Management ■ LANSCE ■ First beam at DARHT-II ■ DANCE ■ PBX 9501 ■

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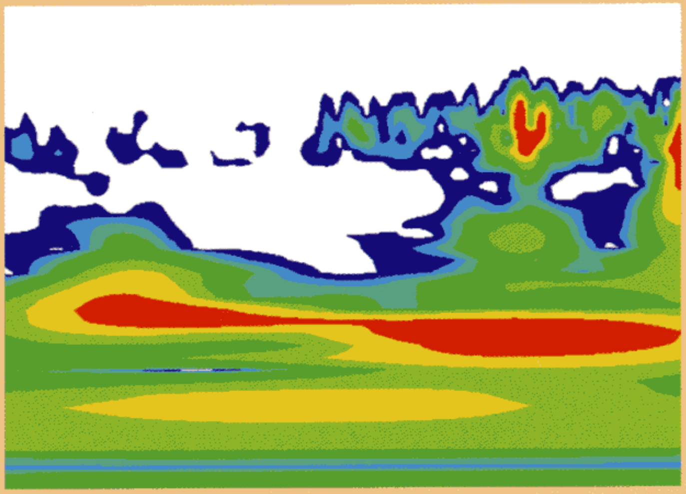

About the cover: Data from the Dual-Axis Radiographic Hydrotest Facility will play a crucial role in stockpile certification. Commissioning of the second axis is in progress: this graphic displays a frequency analysis of beam motion in one experiment during the first commissioning phase, a demonstration that the technology could produce and accelerate a beam of electrons.

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Stockpile Stewardship Contributions by LANSCE in 2002

Overview

The Los Alamos Neutron Science Center (LANSCE) is a unique facility in the national laboratory complex. LANSCE produces the highest-power medium-energy proton beam in the US. The protons are used to radiograph dynamic events or to produce intense pulses of spallation neutrons. The versatility of LANSCE allows scientists to perform experiments in fundamental physics, materials science, nuclear science, and shock physics using proton or neutron irradiation, neutron scattering, and neutron resonance spectroscopy.

The data that result from LANSCE experiments have a direct impact on understanding the physics and materials behavior in a nuclear device

During operations in 2002, LANSCE operated reliably for the National User Program. The user facilities at the Manuel Lujan Center and the Weapons Neutron Research (WNR) facility hosted 224 experiments serving 782 user visits. The proton radiography (pRad) program at LANSCE conducted a very successful campaign that formed the foundation for the most successful year in the history of that program. The LANSCE accelerator once again delivered 100% beam availability for a total of 42 dynamic experiments. Since the inception of proton radiography, the number of pRad experiments has reached 156.

Operated under the direction of Los Alamos for NNSA, LANSCE provides proton and neutron beams for state-of-the-art experiments in three broad areas of research: nuclear science, proton radiography, and materials science. Data taken at LANSCE by the three weapons laboratories, Los Alamos, Livermore, and Sandia, directly impact our understanding of the physics and materials behavior in a nuclear device. These data have many uses. For example, some are incorporated in the Advanced Simulation and Computing (ASCI) codes for device design. Others are used in analyzing data from previous nuclear tests for the Stockpile Stewardship Program. Some of these data are also used for lifetime extension programs and in significant finding investigations. Researchers at LANSCE made significant accomplishments during the 2002 run cycle in all three areas of research.

Nuclear Science

Efforts in stockpile stewardship nuclear science at LANSCE made significant progress over the past year. Major initiatives in this area involved three unique, large detector systems needed to detect products from neutron reactions: the Germanium Array for Neutron-Induced Excitations (GEANIE), the Detector for Advanced Neutron Capture Experiments (DANCE), and the Fast neutron-Induced Gamma Ray Observer (FIGARO). In addition, a new capability to provide neutron radiography as a stockpile surveillance tool is under development.

Radiochemical (radchem) diagnostics play an important role in understanding the detonation of a nuclear device. One method is to measure the amount of specific isotopes produced by the fission process. For example, neutrons impacting the fissionable material can be captured (n,gamma) or can produce secondary neutrons (n,2n) to generate isotopes of the parent nucleus. The ratios of the probability for these reactions relative to the fission probability are well known. Thus, measurement of the amount of ^{238}Pu or ^{240}Pu can indicate the amount of fission that occurred.

Determination of the fusion yield is more difficult because the isotopes produced by neutron interactions with the fusion fuels are not readily discernable. Consequently, some elements or isotopes can be inserted as radchem detectors at various locations in a nuclear device. During detonation, these detectors are subjected to a short and intense flux of fission and possibly fusion neutrons. After the detonation, the radchem detectors and their long-lived activation products are retrieved from the underground explosion site and subsequently analyzed. Many of the reactions for these radchem isotopes have a lower limit, or threshold, for the neutron energy. Neutrons below this threshold do not produce the reaction. By placing several elements with different thresholds into the device, we can infer the energy distribution of the neutrons by measuring the amount of the reaction products. Computational models are then used to match observed amount of isotopes to determine the energy distribution of the neutrons and to provide the fusion yield value.

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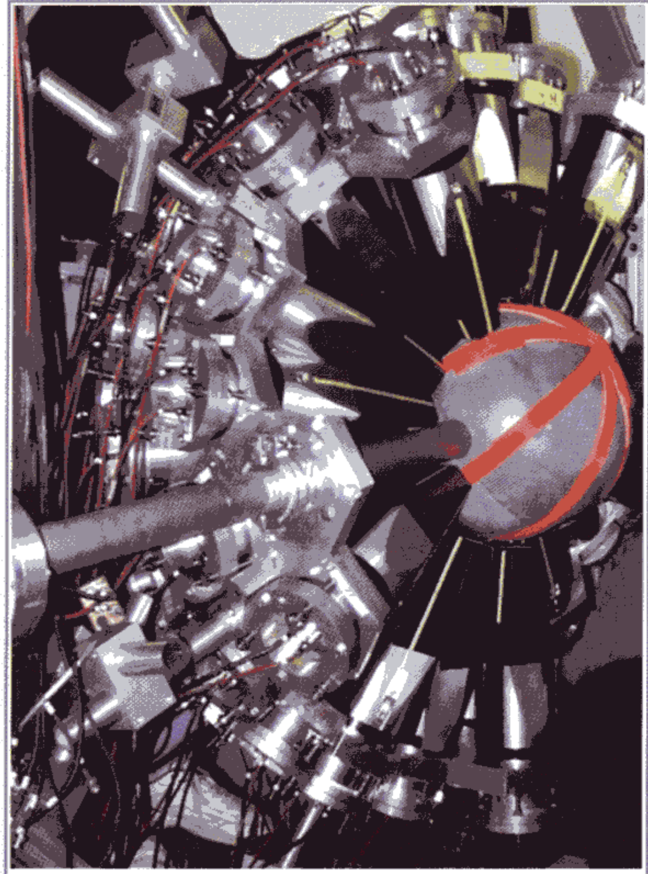
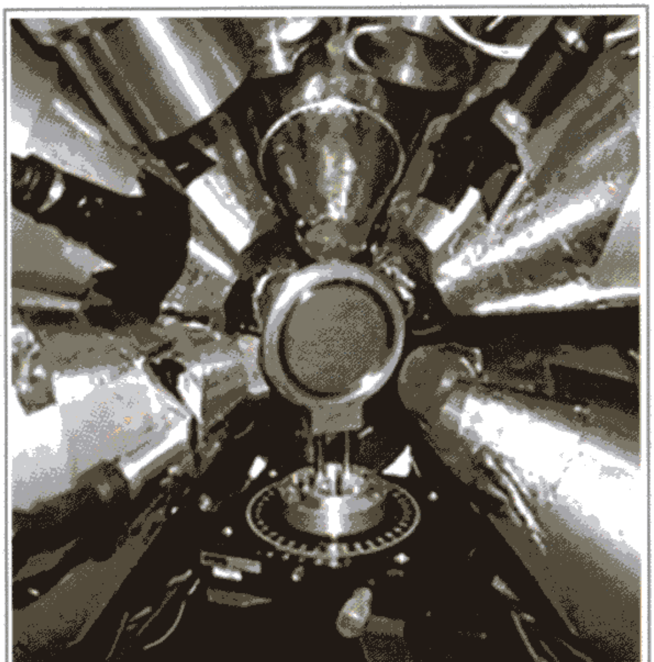


Half of the DANCE neutron capture detector array with the ^{6}LiH ball in the center. The 159 detector elements consist of BaF_2 crystals mounted in phototubes surrounding the center ball that minimizes scattered neutrons reaching the detector elements. The crystals detect gamma rays emitted by neutron capture reactions.

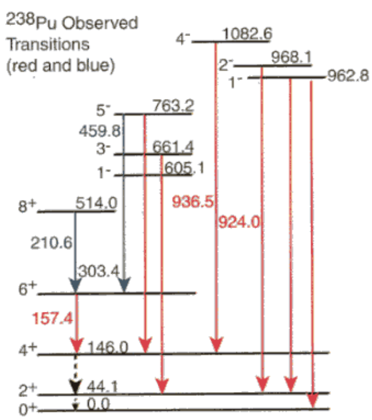
Although many of these radioactive products have short half-lives, their lifetimes are long on the timescale of the explosion. Thus, the buildup and destruction of the reaction products can impact the performance and the diagnosis of the weapon. Accurate measurement of the neutron reaction probabilities, i.e., the neutron cross sections, at LANSCE allows designers running the weapons codes to improve predictions of the radioactive products produced by the explosion.

DANCE is designed to measure neutron-capture cross sections on radioactive targets with masses as low as 0.5 mg. During the 2002 run cycle at LANSCE, we made the first measurements of the neutron-capture cross section of ^{234}U with DANCE. With the intense neutron flux available at the Lujan Center, DANCE is presently the most sensitive instrument for neutron capture experiments in the world.

Fission is the dominant energy-release mechanism in a nuclear device. Understanding the fission process and the products of the process enables accurate modeling of device performance. In addition, understanding the manner in which the fission energy is partitioned into fission products, gamma rays, x-rays, and neutrons improves the modeling of energy deposition profiles in weapons calculations. New measurements of the energy spectra of the prompt neutrons emitted and of the prompt gamma-ray energy spectra are in progress using GEANIE, a large gamma-ray detector array at the WNR facility. In 2002, gamma-ray



GEANIE, a high-resolution spectrometer array located at the WNR, consists of Compton-suppressed, high-resolution gamma-ray detectors. This photograph shows a doubly encapsulated plutonium sample at the center of GEANIE. The GEANIE instrument is used to address issues of nuclear structure, spectroscopy, and cross-section measurements for both stockpile stewardship and basic science.



The $^{239}Pu(n,2n)^{238}Pu$ reaction cross section was determined from GEANIE-measured partial gamma-ray yields (in red) and theoretical calculations. This is new technique for nuclear-reaction cross-section measurements. The measurement was performed by a Los Alamos/Livermore collaboration.

measurements were made on ^{238}U and ^{235}U. Some phenomena of interest include the transition from asymmetric to symmetric fission as a function of excitation energy, competition between neutron and gamma-ray emission, nuclear-structure effects in fission, and the angular momentum imparted to the fission products.

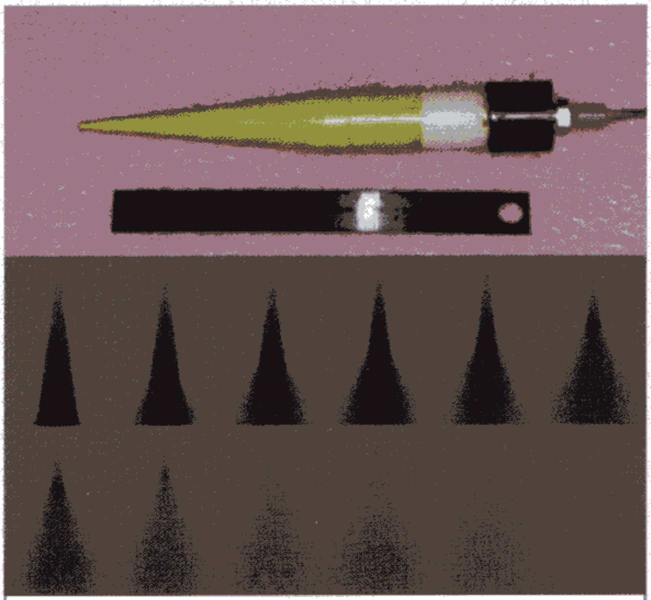
A Los Alamos/Livermore collaboration is now studying the use of iridium and europium (and other isotopes) as radchem detectors. The collaboration has developed a technique for determining activation cross sections over a wide incident-neutron energy range using the GEANIE detector. These activation cross sections, which are difficult to obtain by other means, are needed to better understand the detonation of nuclear devices and in other applications for which neutron-fluence measurements are required. For example, data obtained with GEANIE extend beyond the range of neutron energies produced in a nuclear device, and, consequently the data have application in systems for transmutation of nuclear waste or in other high-energy systems that use neutrons.

Although most of the efforts in nuclear science for weapons revolved around nuclear interactions in the device, LANSCE also made significant contributions in the world of large-scale computing. The ASCI Q machine is one of the most powerful supercomputer systems in the world. The first 10-TeraOPS (10 trillion floating-point operations per second) segment of the Q machine was made available to the users in the secure environment in August 2002. This machine was used to complete a Los Alamos ASCI milestone calculation for NNSA in December 2002 for which the Shavano Code Project Team recently won the Laboratory's Distinguished Performance Award.

Shortly after the Q machine became operational, it was discovered that the machine was failing more frequently than predicted. The cause of these failures was not obvious, and the many possible reasons for failures included hardware and software. One possible cause for these failures was thought to be random upsets (bit-flips) in one type of memory cache caused by cosmic rays interacting with nuclei in the upper atmosphere to create neutrons that interact with the material in the semiconductor devices.

A team from LANSCE-3 and P-23 assembled a neutron detector and placed it in the computer room to measure the neutron flux in the computer room environment. To address the system response, a second team consisting of staff from LANSCE-3 and Hewlett-Packard began testing a single module of the Q machine at the WNR neutron source. The WNR neutron source has the unique feature that its neutron spectrum closely matches the spectrum of neutrons produced by cosmic rays interacting with the atmosphere. The intensity of the WNR neutron beam is, however, approximately 10^8 times more intense. The results of the tests strongly indicate that a large part of the failure rate is due to single-event upsets caused by cosmic rays. These measurements solved the mystery of the Q machine failure rate and suggest possible mitigation strategies.

Finally, researchers in P-23, using the LANSCE beam to produce short bursts of neutrons, extended the application of a new measurement technique that allows a determination of the temperature of material behind a shock front. During the last run cycle, the Neutron Resonance Spectroscopy (NRS) team performed four dynamic experiments to measure the temperature in an explosively formed copper jet. The experiments were aimed at testing models of metals under high strains and strain rates. In a second experimental thrust, the first in a series of NRS experiments was performed to measure the temperature behind the burn front of detonating high explosive (HE) doped with a neutron-absorbing material. The test series uses samples made by a new method that reduces dopant granularity within the samples. Present theoretical uncertainties in the temperature are quite large, and a precise measurement will greatly improve the characterization of the equation of state of detonating HE.



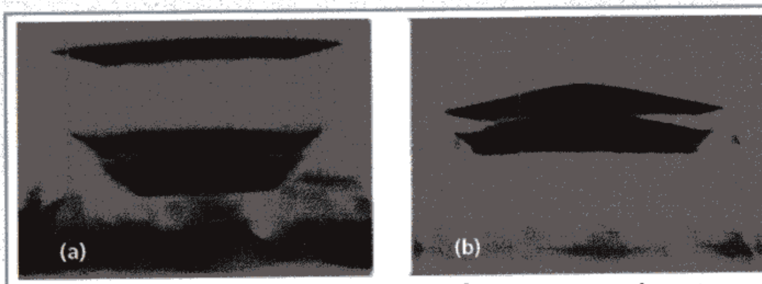
Proton radiography "movie" of detonating HE: (above) failure cone designed to study the detonation characteristics of the high explosive PBX 9502; (below) proton radiographs at various times throughout the detonation of the failure cone showing characteristics of the detonation front as it propagates to the end of the failure cone.

Proton Radiography

Historically, the nuclear weapons program has utilized pulses of x-rays to take pictures of device components as they were imploded by HE, i.e., dynamically. This capability has recently been improved with the construction of the Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility at Los Alamos. DARHT has the capability to see through dense, imploding devices using an intense pulse of high-energy x-rays. Currently, DARHT has the ability to take a single "snapshot" of the imploding system.

Many of the questions of interest to stockpile stewardship, however, are time-dependent and require images taken at different times in the implosion. By using the multiple pulses of protons available at LANSCE, a sequence of pictures can be produced that shows the contours of dense materials as they implode. Consequently, even though the 800-MeV protons currently provided at LANSCE cannot "see through" as much material as DARHT x-rays can, pRad is an excellent complement to the DARHT capability. The data taken at both the DARHT and pRad facilities are compared to calculations using weapons hydrodynamic codes to validate the algorithms used for weapons design.

The pRad program under group P-25 is investigating weapons-physics issues related to the detonation of HE along with the equation of state (EOS) of the burned HE products, the dynamic failure processes such as spall and shear banding of explosively driven metals, and the hydrodynamics of implosions.This program provides the unique capability of studying the evolution of explosive processes with high spatial and temporal resolution.



Proton radiographs from two November 2002 experiments studying 316L stainless steel shocked to failure: (a) 1/2-in.-thick steel; (b) 1/4-in.-thick steel. Proton radiography provides the unique capability of studying the evolution of explosive processes with high spatial and temporal resolution.

In 2002, 42 dynamic pRad experiments—a run-cycle shot record—were performed at LANSCE in support of the weapons-physics efforts at Los Alamos, Sandia, Livermore, and the Atomic Weapons Establishment (AWE) at Aldermaston, England, bringing the total number of dynamic pRad experiments performed at LANSCE to 156. For these shots, the LANSCE accelerator and beam-delivery complex provided protons with 100% reliability. In addition to these dynamic experiments, beam time was used for detector and concept development and for the radiography of static mockups to determine shot configurations and the design of future experiments.

The 42 pRad shots in 2002 fell into three categories: outside-user experiments, studies of HE burn characteristics, and studies of material failure mechanisms such as spall and shear banding. Two experiments were fired for Sandia to continue investigations on the dynamics of explosively driven voltage bars used for neutron generators. Three experiments were performed with Livermore to study the material-failure characteristics of steel under various shear- and stress-dynamic-loading scenarios. A sixth dynamic experiment was performed with AWE to investigate the bonding strength of a thin lead layer bonded to an aluminum disk.

Of the 42 dynamic experiments, 18 were devoted to the study of HE burn characteristics. Three of these experiments were designed to study the EOS of HE burn products, two measured the width of the HE detonation zone in PBX 9501 and PBX 9502 high explosives, and the remaining experiments were designed to study the characteristics of detonating HE. An experimental series named AFX-221 was performed for the US Air Force to study burn characteristics around objects embedded within HE. Nine dynamic experiments were performed to study the spall-formation process in aluminum, copper, tin, and 316L stainless steel. Two experiments were performed to study the fracture mechanisms of thin cylinders of titanium. A classified experiment involved a configuration containing the largest HE load (~10 lb) ever fired at LANSCE. This experiment is being carefully simulated on computers to provide model data for comparison to the data collected with pRad.

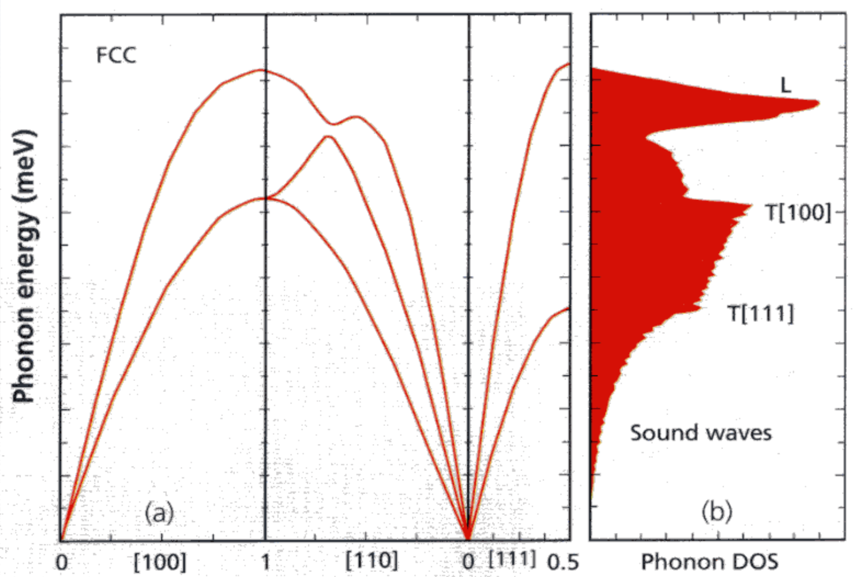
During the 2002 run cycle, LANSCE-1 designed and built a new high-gradient, permanent-magnet microscope, which was successfully tested by the pRad team. The design of this new permanent-magnet-quadrupole (PMQ) microscope system was part of a larger Laboratory-Directed Research and Development project to develop a pRad capability to study phenomena on a 10-µm scale. The pRad microscope was commissioned in the fall of 2002. This microscope system was designed to improve the radiographic resolution to study the mesoscale properties of dynamic systems. The commissioning effort was very successful in improving the resolution from the 200 mm achieved with the standard radiography system to 18 mm.

Weapons Materials Science

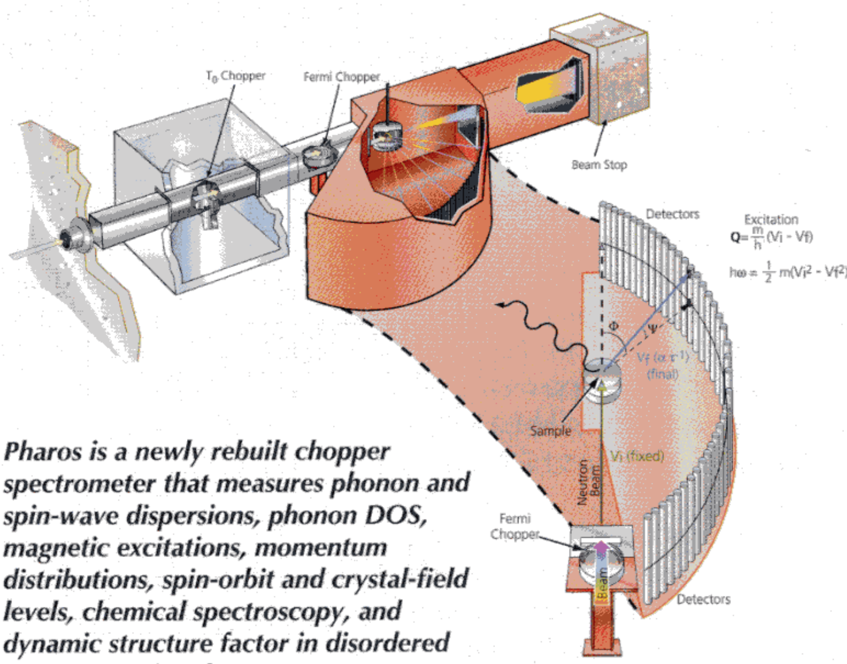
Stockpile Stewardship Program research at LANSCE that focuses on weapons materials science takes advantage of the powerful suite of instruments and intense neutron beams available at the Lujan Center. Scientists have made excellent progress on a number of key weapons materials issues in the areas of

- plutonium aging and phase stability,
- EOS of plutonium and other weapons materials with future emphasis on measurements at high pressure and temperature,
- constitutive properties of weapons materials (including plutonium) via microstructure characterization (e.g., crystallographic texture), and
- component lifetime assessment and manufacturing benchmarking provided by measurements of applied and residual strain and other techniques.

The solid-state properties of plutonium are significantly more complicated than those of most other metals. These complex physical properties arise from the role of the 5f electrons in the chemical bonding between atoms. One possible way to



The three connected panels (a) show the typical phonon dispersion curves expected for a face-centered cubic (fcc) metal along certain symmetry directions. Panel (b) shows the phonon densities of states (DOS) of nickel calculated from the same model.

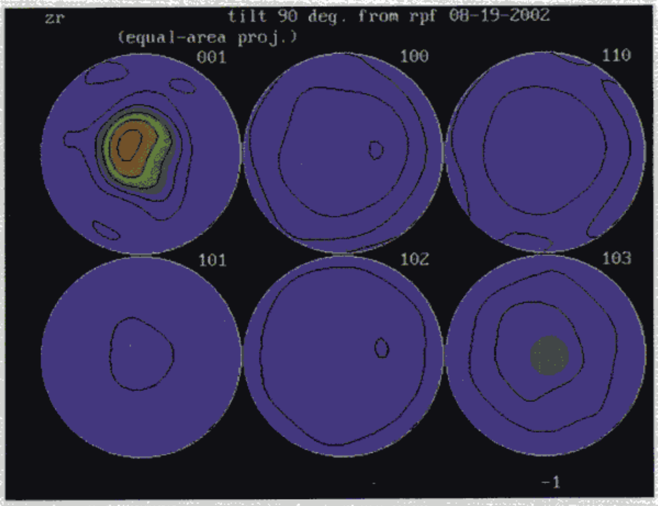


Pharos is a newly rebuilt chopper spectrometer that measures phonon and spin-wave dispersions, phonon DOS, magnetic excitations, momentum distributions, spin-orbit and crystal-field levels, chemical spectroscopy, and dynamic structure factor in disordered systems. During the 2002 LANSCE run cycle, researchers used Pharos to perform inelastic-neutron scattering from a plutonium-aluminum alloy and extracted the first-ever phonon DOS.

verify the accuracy of electronic-structure calculations is through the measurement of the phonon dispersion in the different phases of plutonium. Phonons are the normal modes of atomic vibration on a crystal lattice. The frequency of a particular phonon depends on the wavelength and displacement pattern of the atom's motion and the forces acting between atoms. These forces arise entirely from the bonding properties and are a stringent test of first-principles electronic-band-structure calculations.

Inelastic-neutron-scattering (INS) measurements from single crystals of plutonium directly give the phonon dispersion. However, single-crystal samples of sufficient size (~1 cm^3) for this technique are not presently available. From polycrystalline samples, we can obtain the phonon densities of states (DOS), which contains a complete description of the lattice thermodynamics and information about the interatomic forces. We were able to obtain ~35 g of $Pu_{0.95}Al_{0.05}$ enriched to 95% ^{242}Pu (the ^{242}Pu isotope is necessary to reduce absorption). The DOS for $Pu_{0.95}Al_{0.05}$ was measured for the first time ever at several temperatures using the Pharos spectrometer at LANSCE. The phonon graph at the top of page 15 shows a schematic of DOS data.

Similarly, a detailed understanding of the stress-induced texture evolution and phase transformations that occur during shock loading of weapons materials is central to understanding and accurately modeling the underlying implosion physics in nuclear weapons. Phase transitions in weapons materials, especially if associated with a large volumetric change, can profoundly affect material states and constitutive, damage, and fracture properties during implosion. For example, during the 2002 run cycle at LANSCE, shock-induced changes in a sample of high-purity zirconium were examined using neutron diffraction with the High-Intensity Powder Diffractometer (HIPD). Zirconium exhibits a subset of the extremely complex dynamics and phase-stability behavior exhibited by materials relevant to stockpile stewardship, to the Stockpile Life Extension Program, and to core elements of the Nuclear Weapons Technology Program. The goals for the zirconium studies were to develop models of the EOS and strengths of weapons materials and to improve our understanding of the fundamental physics and materials science of nuclear weapons.



Zirconium undergoes shock-induced phase transformations from the hexagonal α phase to the metastable ω phase. This HIPD neutron diffraction result shows the texture of zirconium following shock above the α–ω phase transition (at 8.0 Gpa). Below this transition, there was no evidence of the presence of the ω phase.

The LANSCE 2002 run cycle included many more experiments than have been briefly described in this article. The emphasis here is on those experiments that relate directly to the Stockpile Stewardship Program. A more comprehensive review of the unclassified research at LANSCE can be found in the *CY2002 LANSCE Activity Report* (LA-14036-PR). ✸
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